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AFSC No.

EIGHTH INTERIM TECHNICAL PROGRESS REPORT

MANUFACTURING TECHNOLOGY LABORATORY

DIRECTORATE OF MATERIALS

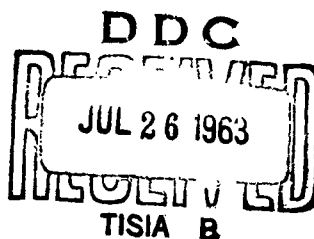
AND PROCESSES

AFSC AERONAUTICAL SYSTEMS DIVISION

**TUNGSTEN FORGING
DEVELOPMENT PROGRAM**

CONTRACT No. AF 33(600)41629

19 MAY 1963



MATERIALS PROCESSING DEPARTMENT

TAPCO
A DIVISION OF

Thompson Ramo Wooldridge Inc.

CLEVELAND 17, OHIO

410145



TAPCO a division of
Thompson Ramo Wooldridge Inc.

ASD TR 7-797 (VIII)

ASD INTERIM REPORT 7-797 (VIII)
May 1963

TUNGSTEN FORGING DEVELOPMENT PROGRAM

E. J. Breznyak

Materials Processing Department
TAPCO a division of
THOMPSON RAMO WOOLDRIDGE INC.
Contract: AF 33(600)-41629
ASD Project: 7-797

ASD Project Engineer: L. C. Polley

Eighth Interim Technical Progress Report
19 February 1963 - 19 May 1963

A scaled-up thin section configuration and tooling sequence for verification of the Phase V forging process has been designed. Arc melted and extruded tungsten billet stock has been procured to specification. Billets of hot-cold worked and recrystallized structures are to be forged and evaluated.

MANUFACTURING TECHNOLOGY LABORATORY
DIRECTORATE OF MATERIALS AND PROCESSES
AFSC Aeronautical Systems Division
United States Air Force
Wright-Patterson Air Force Base, Ohio



TAPCO a division of
Thompson Ramo Wooldridge Inc.

ABSTRACT - SUMMARY

ASD TECHNICAL REPORT 7-797 (VIII)
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Eight Interim Technical Progress Report

TUNGSTEN FORGING DEVELOPMENT PROGRAM

E. J. Breznyak

Materials Processing Department
TAPCO a division of
THOMPSON RAMO WOOLDRIDGE INC.

ASD Project Engineer: L. C. Polley

A scaled-up thin section configuration and tooling sequence has been designed to verify the forging process developed during Phase V and to demonstrate that mechanical properties can be controlled during scale-up. The forging tooling has been manufactured.

Arc melted and extruded unalloyed tungsten has been selected as the forging billet material. The extruded billet stock has been procured to specification.

The initial forging trials will include billets of hot-cold worked and recrystallized structures to be used for forgeability and property evaluation.



TAPCO a division of
Thompson Ramo Wooldridge Inc.

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FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF 33(600)-41629 from 19 February 1963 to 19 May 1963. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This contract with the Materials Technology of TAPCO a division of Thompson Ramo Wooldridge Inc., Cleveland, Ohio was initiated under ASD Project 7-797, "Tungsten Forging Development", It is administered under the direction of Mr. L. C. Polley of the Manufacturing Technology Laboratory, Directorate of Materials and Processes, AFSC Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

E. J. Breznyak of the Materials Processing Department, TAPCO a division of Thompson Ramo Wooldridge was the Engineer in charge. F. N. Lake also contributed to the program.

PUBLICATION REVIEW

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I INTRODUCTION

The use of tungsten for ultrahigh temperature components in aerospace vehicles is still a relatively new concept. Only since projected operating temperatures have reached 3000°F and above has the density of tungsten been viewed as anything but undesirable. The success of rocket nozzle engineers in designing around tungsten's density has further prompted a re-evaluation of the applicability of tungsten as a material for load carrying structural components.

The basic manufacturing method for aerospace structural components is forging. For tungsten, however, forging methods did not exist except as related to conversion steps in the lamp industry and as used for preliminary rocket nozzle shaping. For this reason the Aeronautical Systems Division, Manufacturing Technology Laboratory, initiated the present program with Thompson Ramo Wooldridge for the development of forging methods for tungsten and its alloys.

The principal objective of the program was the development of methods for producing tungsten forgings for structural use in aerospace vehicles. To accomplish this aim the program was originally divided into five phases consistent with the state-of-the-art and with the non-integrated nature of the refractory metal and forging industries. The objectives of each of these original five phases are summarized below:

Phase I State-of-the-Art-Analysis

An evaluation of the tungsten and forging industry state-of-the-art in order to satisfactorily plan the program for subsequent phases. This was completed and reported in the First Interim Technical Progress Report on 31 August 1960.

Phase II Billet Process Development

The development of processes for the production and conversion of sound tungsten ingots to quality forging bar stock. This was completed and reported in the Second Interim Technical Progress Report on 12 December 1960.

Phase III Development of the Forging Operation

The forging of tungsten billets to establish forging process parameters, controls, and tests for the controlled forging of tungsten. This was completed and reported in the Third and Fourth Interim Technical Progress Reports on 27 March and 27 May 1961 respectively.



Phase IV Forging Process Verification and Post-Forging Development

Forging tungsten to verify the developed process and the subsequent development of applicable post-forging operations. This was completed and reported in the Fifth Interim Technical Progress Report on 9 November 1961.

Phase V Final Pilot Production

Pilot production to demonstrate reliability of the developed process and of the forgings produced. This phase was successfully completed with Phase IV and also reported in the Fifth Interim Technical Progress Report.

That all of the program objectives were met is well documented (1-5). In addition, the original objectives of Phases III, IV, and V; i.e., those of development and pilot production verification of controlled precision forging methods for structural tungsten components, were accomplished within the boundaries of the third and the fourth phases. For these reasons the program has been modified and extended for adaptation of the developed technique to the continuing and more immediate problem of thin section, nonstructural tungsten shapes currently required by the rocket engine industry. The specific objectives of the revised fifth phase and the additional sixth phase are:

Phase V Development of Thin Section Forging Process

Extension of the developed forging process to controlled precision forging of thin section, nonstructural tungsten shapes having optimum properties.

Phase VI Verification of Thin Section Forging Process

Production of scaled-up thin section forgings to verify and demonstrate applicability of the process.

This Eighth Interim Technical Progress Report covers approximately the first half of the Phase VI program effort.



II PHASE VI PROGRAM

The objective of Phase V was adaptation of the process developed for structural forgings to thin section tungsten components presently required for aerospace applications. That the objective has been successfully achieved has been demonstrated^(6, 7), i.e., the evaluation of the close tolerance forging sequence developed showed dimensional reproducibility, excellent as-forged surfaces, and desirable grain flow orientation in the final thin section components. The Phase VI objective is to verify this thin section tungsten forging process, developed during Phase V, by scaling up to a larger specific thin section design. The principal criterion to be used for judging the universal applicability of the forging process is the extent to which the mechanical properties of the thin section forging can be controlled and maintained during scale-up. The tasks scheduled for accomplishing the Phase VI objectives are:

1. Design of a scaled-up configuration and tooling sequence compatible with both previous design and process data and the requirements of the aerospace industry for thin section tungsten components in the 50 to 70 pound range.
2. Selection and procurement of arc melted and extruded forging billets.
3. Development of the scaled-up forging process to provide optimum properties in the thin section component.
4. Property determination and evaluation of the scaled-up thin section tungsten component.

The organization of these interrelated tasks into the Phase VI program effort is illustrated schematically in Figure 1.



PHASE VI VERIFICATION OF THIN SECTION FORGING PROCESS

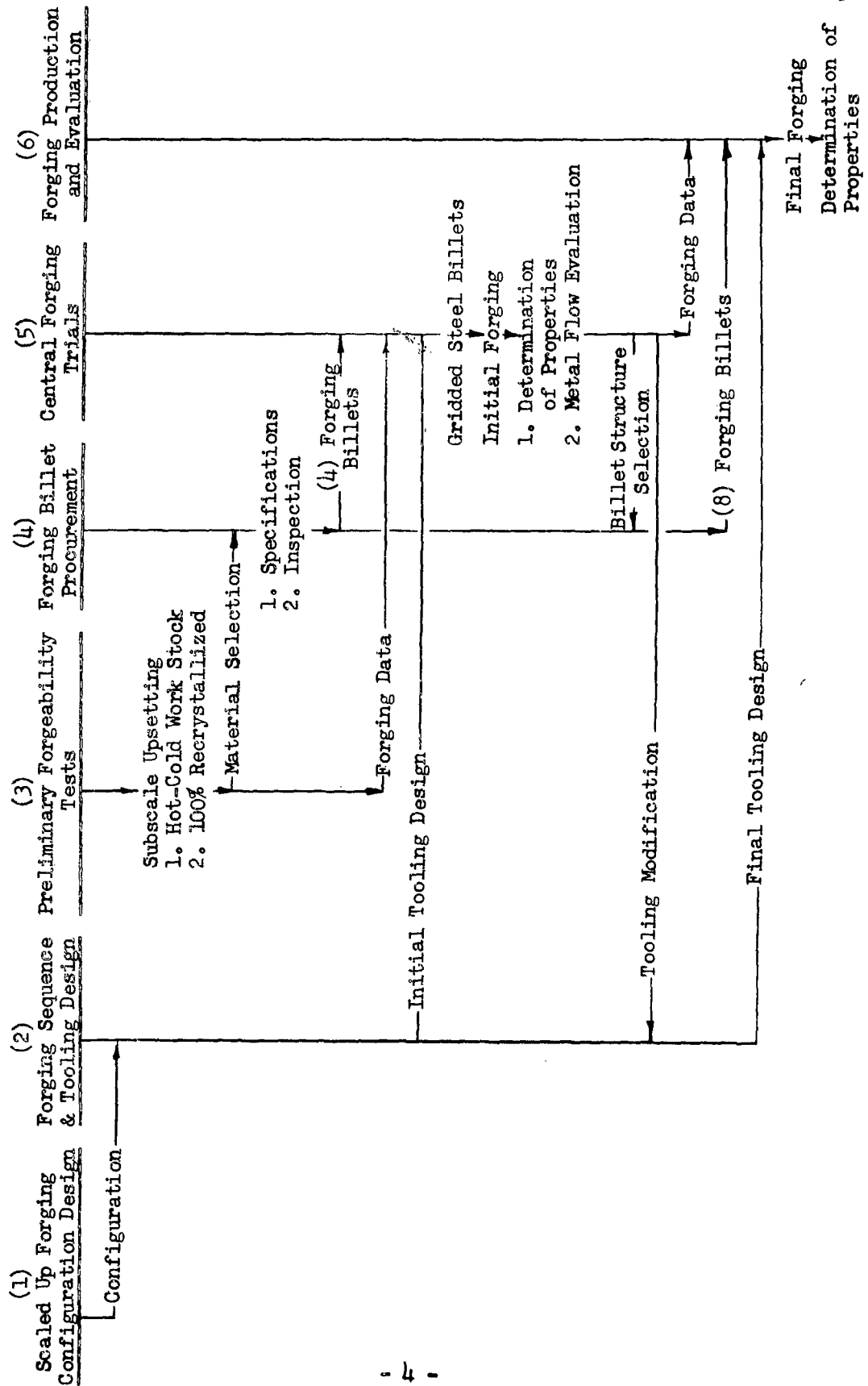


Figure 1. Plan of Operations and Programming for Phase VI



III SCALED-UP THIN SECTION DESIGN

A. Configuration

The universal thin section forging developed during Phase V resulted in an experimental design capable of permitting full range evaluation of the major processing parameters in thin section forging. The configuration selected was the result of evaluation of data, recommendations, and insert prototypes gathered by a TAPCO survey team from organizations⁽⁶⁾ known to be active in aerospace applications. Prior to the scale-up design effort, these same organizations were again contacted, this time with respect to forgings in the 50 to 70 pound range. The results were comparable to the initial inquiry, i.e., no consistent pattern of configuration design or absolute values of physical or mechanical properties could be resolved. Therefore, in keeping with previously detailed⁽⁶⁾ conclusions and recommendations pertinent to thin wall nozzle insert technology, the scaled-up thin section forging shown in Figure 2 was designed. Observation of the scaled-up design indicates the severity of the configuration, e.g., the forging base area (cup bottom) has been scaled-up by a factor of three over the initial thin section design while the wall thickness has remained essentially unchanged. The restrictions imposed by such a configuration will provide a good measure of the ability of the process developed for thin section design to control and provide optimum properties in the forged component.

B. Forging Sequence

Design of the scaled-up thin section configuration established the forging billet volume requirement at 72 in.³. The next Phase VI task, that of selecting and designing a tooling sequence, fixed the forging billet size to 3-3/4" diameter by 6-1/2" long. This billet size represents a direct scale-up of the length to diameter ratio of 1.7 established for the Phase V forging billets.

During Phase V, the forging sequence development effort⁽⁷⁾, showed a minimum of five forging blows was required for the production of sound forgings. The initial forging operations (upsetting) provide lateral metal flow in a direction normal to that of extrusion and were accomplished in a two blow sequence during Phase V. However, the scaled-up sequence consists of a total upset deformation requirement of 70% as compared to 59% for the Phase V sequence. Therefore, a third upsetting operation was added, resulting in a total of six forging steps. This six-step forging sequence designed for the scaled-up thin section configuration is illustrated in Figure 3. The three latter forging steps (back extrusion) provide the vertical metal movement necessary to produce the side walls of the cup-shaped forging.



CROSS SECTION OF SCALED UP FORGING CONFIGURATION

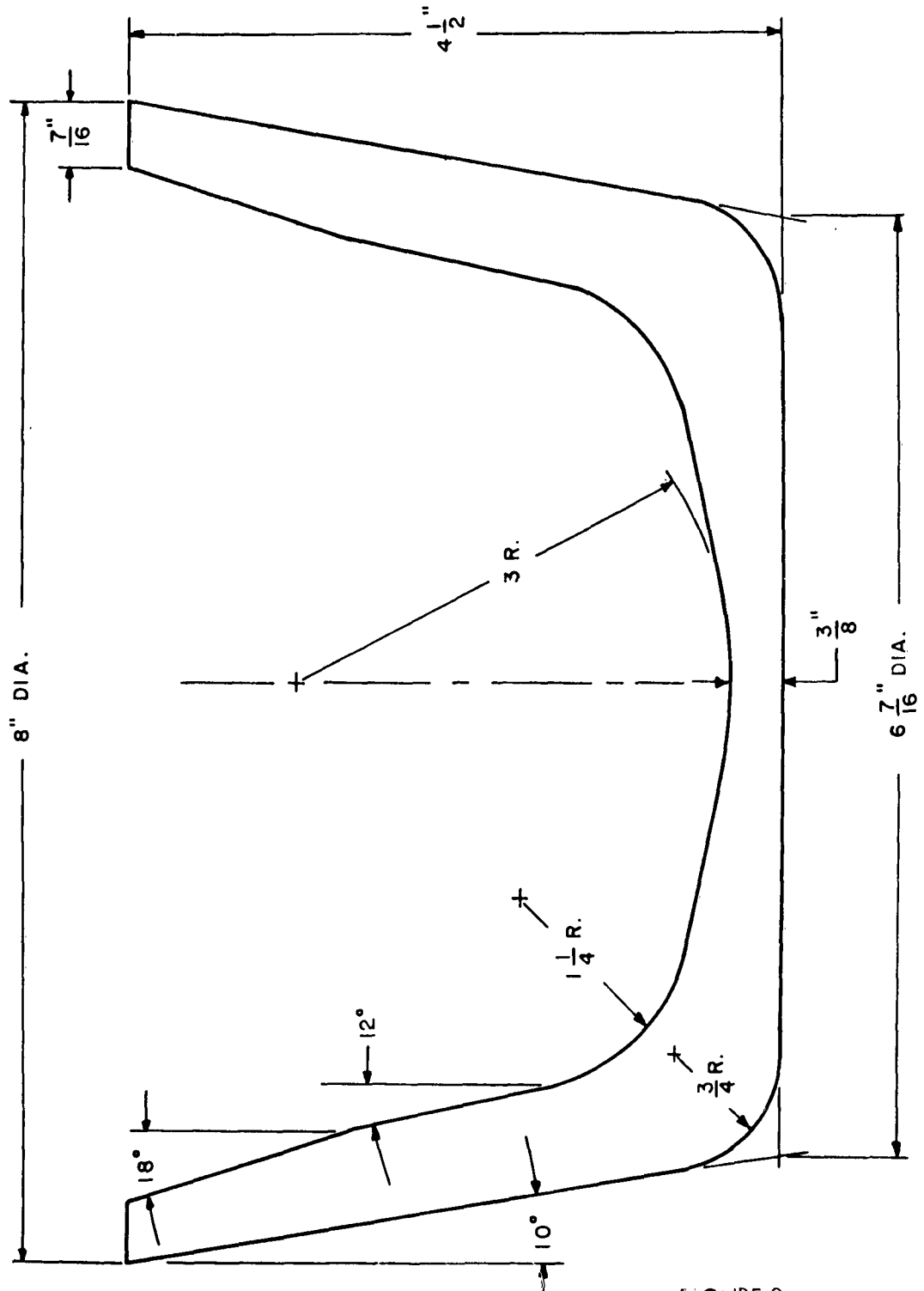


FIGURE 2



FORGING SEQUENCE FOR SCALED UP CONFIGURATION

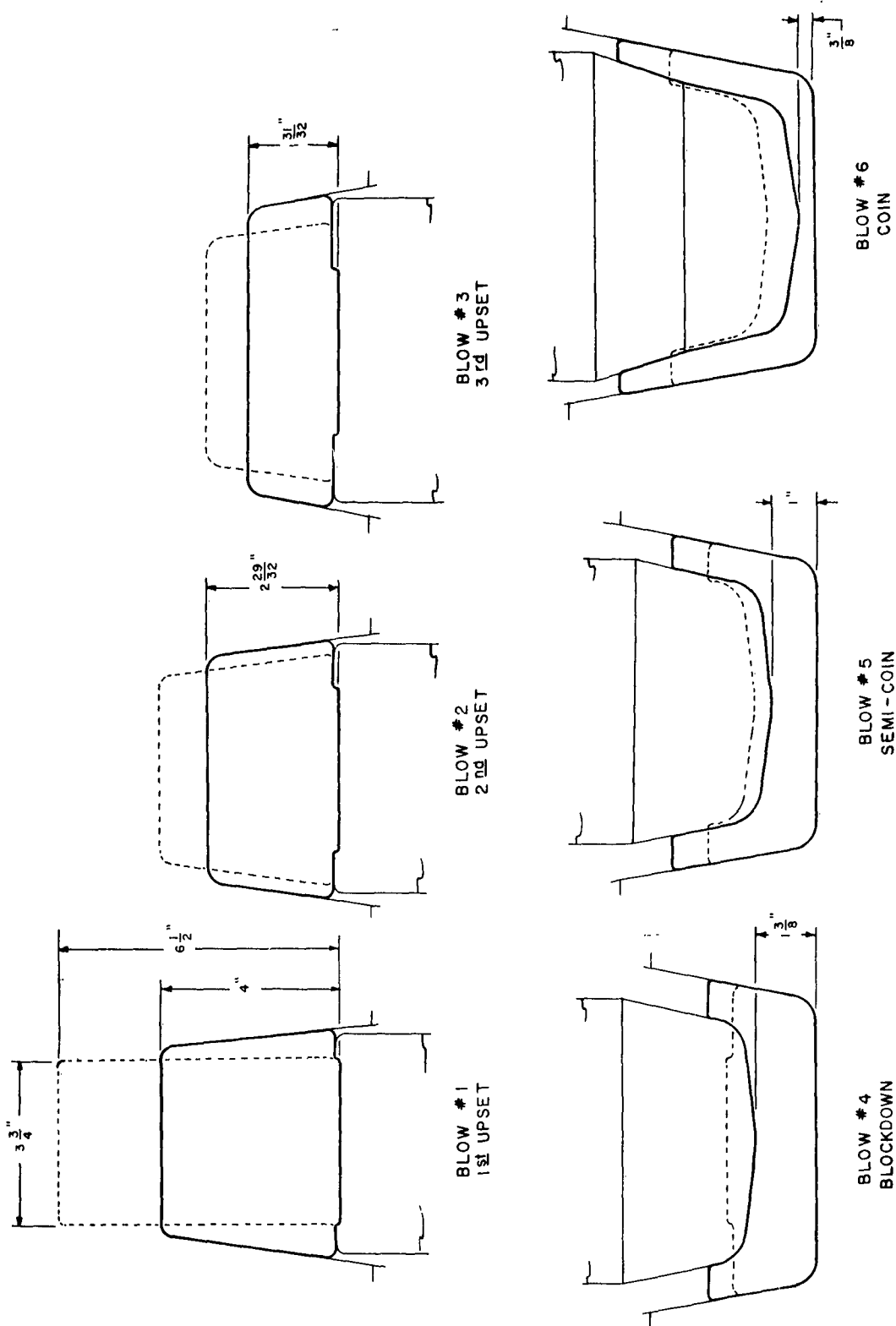


FIGURE 3



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The flexibility of the sequence developed during Phase V has been maintained during scale-up, i.e., a direct comparison can be made of the effect of reduction of the number of forging steps on material forging response and the ultimate properties of the forged component.



IV FORGING BILLET PROCUREMENT

Because of the high service temperature requirements of rocket nozzle inserts, materials selection as previously reported⁽⁶⁾ is limited to unalloyed tungsten or tungsten containing dilute solid solution alloying elements. During Phase V all commercial melters and extruders were invited to produce cast-extruded unalloyed tungsten or W-2%Mo forging billets to the established 2-3/4" diameter requirement. Since all organizations declined, the program undertook the responsibility for both ingot procurement and the subsequent extrusion to forging billet stock.

These organizations were again contacted with respect to Phase VI requirements. A tentative specification was submitted with a quotation requested for 3-3/4" diameter cast-extruded forging stock and/or cast ingots 8" diameter by 12-15" long of unalloyed tungsten or W-2%Mo. Extrusion billets of centrifugally cast W-2%Mo produced by Oregon Metallurgical Corporation for Phase V could not be procured to the Phase VI, 8" diameter requirements. Although Oremet is currently planning to scale-up their casting facility to produce ingots of this size, they were not able to meet the delivery requirements of this phase of the program.

Climax Molybdenum Company of Michigan offered to attempt to supply arc cast and extruded unalloyed tungsten forging billet stock to the required 3-3/4" diameter. Climax accepted a firm order for twelve extruded billets to a rigid specification. The specification, reproduced in Appendix I, closely controls ingot and extrusion processing and forging billet quality, e.g., acceptance is contingent upon meeting specified billet chemistry, non-destructive testing, dimensions, surface finish, and microstructure requirements.

A. Extrusion

Climax melting practice consists of the PSM process in which the powder is pressed, resistance sintered, and continuously fed into the melt⁽³⁾. Four ingots were melted by Climax and extruded at the Metals Center facility, E. I. du Pont de Nemours & Co. The ingots were extruded through an 8" container at a reduction ratio of 3.5/1 within a temperature range of 3100-3150°F. The extrusions were immediately buried in silocel for a slow cool to room temperature to minimize thermally induced stresses.

B. Extrusion Results

The TAPCO specification dictated that the billets were to be supplied in a fully cold worked and stress relieved condition. Therefore, Climax sectioned slices from the lead ends of the four extrusions for a stress



relief temperature determination. Metallographic examination of the lead slice microstructures revealed a considerable degree of recrystallization in the as-extruded condition. The four extrusions were heat treated for one hour at the 2500°F stress relief temperature established with the lead end slices. The as-extruded lead end microstructures of the four extrusions* are shown in Figures 4, 5, and 6. After examination of the microstructure the following was concluded:

1. Extrusion No. TRW-1 was approximately 80% recrystallized with some evidence of cold worked structure remaining at the extrusion center.
2. Extrusion Nos. TRW-2 and 4 were approximately 70% cold worked from the extrusion surface to 1/3 of the radius inward. Between 1/3 and 2/3 inward from the surface, the extrusion was approximately 50% recrystallized. The degree of recrystallization in the remaining center section varied from 0 to 20%.
3. Extrusion No. TRW-3 showed only slight signs of recrystallization and was approximately 95% cold worked.

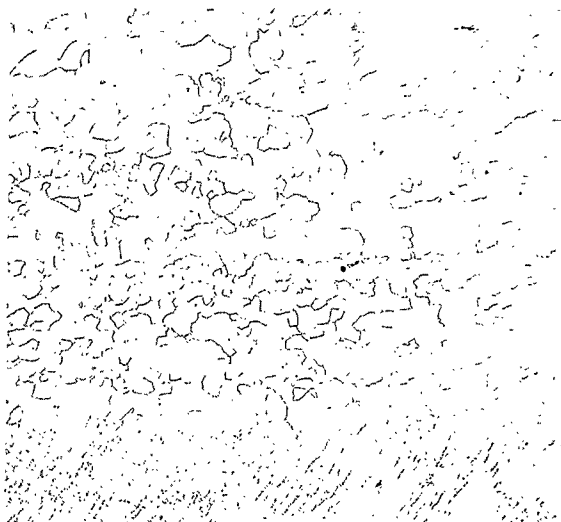
In addition, a comparison of the microstructures indicated the grain size of the cast and cold worked structure to be larger by at least one order of magnitude than that of the recrystallized structure. This marked grain size variation indicated the desirability of performing preliminary forgeability tests to evaluate the response to deformation of the two structures.

C. Upset Forgeability Tests

Upon request, Climax supplied TAPCO Materials Processing Department with two 1-1/4" thick half sections from the butt end of extrusion No. TRW-3. One of the half sections was recrystallized at 2900°F for 1 hour while the other half section was stress relieved at 2500°F for 1 hour. The representative microstructures of these sections are shown in Figure 7. The more uniform structure exhibited by the recrystallized section as compared to the stress relieved section is apparent. Although portions of the center section in Figure 7b appear to be unrecrystallized, an examination at higher magnification show these coarse grains to have a fully developed substructure.

- - - - -

* TAPCO extrusion number designations - TRW-1 thru 4.



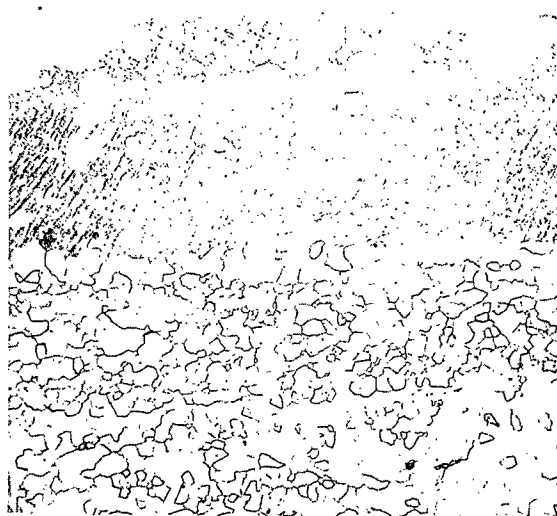
SURFACE

07193



CENTER

07195



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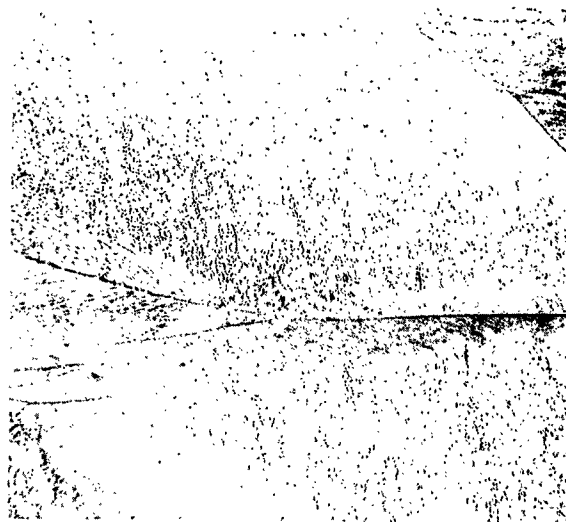
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**AS EXTRUDED MICRO STRUCTURE OF LEAD SLICE
OF EXTRUSION NO. TRW-1**



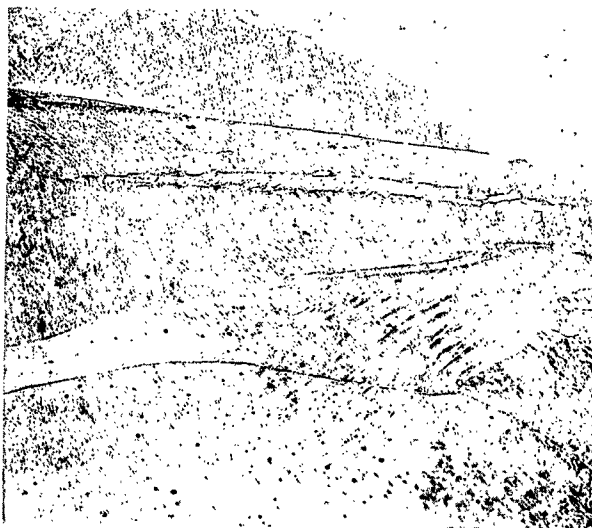
SURFACE

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07196

AS EXTRUDED MICRO STRUCTURE OF LEAD SLICE
OF EXTRUSION NO. TRW-3

50X

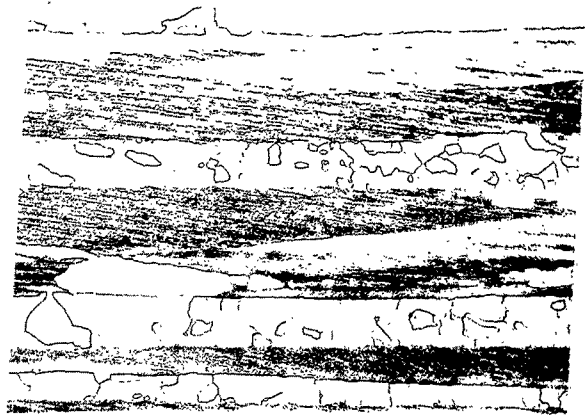


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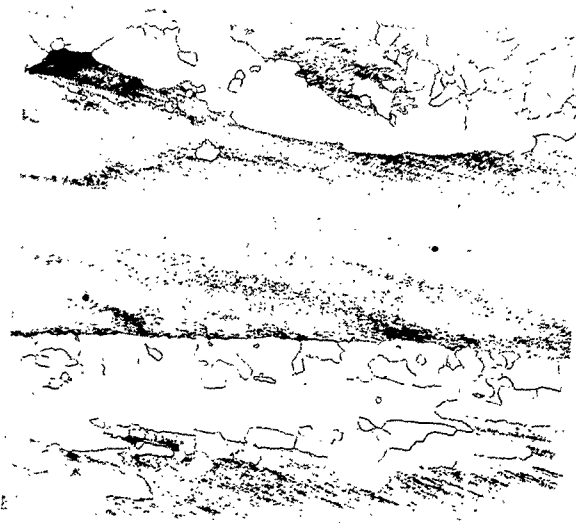
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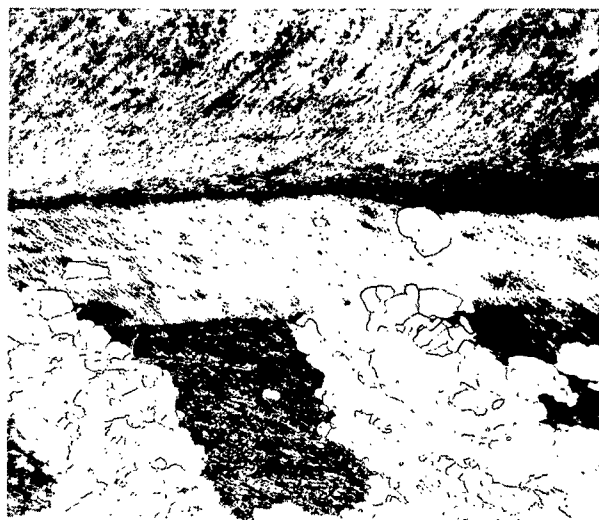
07212

REPRESENTATIVE AS EXTRUDED MICRO STRUCTURES OF
LEAD END OF EXTRUSION NOS. TRW-2 AND TRW-4

50X

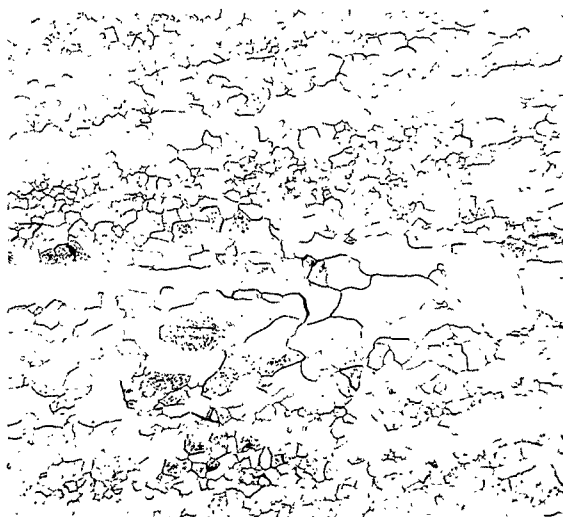


SURFACE 07211



CENTER 07210

A) Stress Relieved at 2500°F for 1 hour



SURFACE 07199



CENTER 07203

B) Recrystallized at 2900°F for 1 hour

MICRO STRUCTURES OF STOCK SECTIONED FROM BUTT END OF
EXTRUSION NO. TRW-3 AND HEAT TREATED AS INDICATED

50X



Four slugs of 1" diameter by 1" long were machined from each section. The slugs were upset 50% at temperatures ranging from 2200°F to 2800°F. The upset slugs shown in Figure 8 appeared to forge well and no surface differences were visually apparent within the test temperature range. However, metallographic examination of sectioned slugs indicated upsetting the stress relieved slugs resulted in a non-uniformly worked structure (Figure 9) in comparison to the recrystallized and upset stock. Since the ultimate component microstructure and mechanical property control and reproducibility are strongly inter-related, the results of the upset forgeability testing suggest the need for initial structure uniformity in the forging billet.

D. Billet Selection

The specification as dictated by the previous program phases required forging of stock with a fully cold worked microstructure. Since the observed as-extruded microstructures were partially recrystallized and did not meet the specification requirements, three approaches towards solution of the problem were apparent as follows:

1. Total rejection of the order for twelve billets. This would delay the Phase VI program by a minimum of six months. Climax indicated that they would be willing to melt additional ingots if TAPCO would undertake the responsibility for extrusion. Immediate contact with other tungsten sources revealed that they could not yet guarantee melting of sound ingots of the size required.
2. Total acceptance of the order regardless of microstructure. This approach risks Phase VI objectives by allowing possibility of production of forgings with non optimum mechanical properties.
3. Acceptance of four billets to be forged and fully evaluated prior to acceptance or rejection of the remaining eight billets. Climax indicated that the remaining eight billets would be held in reserve until such time as the forging and property evaluation of the four billets was completed.

It was believed that the third approach would give maximum opportunity to both accomplish Phase VI program objectives and to maintain the program on a consistent time schedule. Therefore, four billets were ordered from Climax; two billets of recrystallized structure and two billets of as-extruded and stress relieved, hot-cold worked structure. As the extrusions were being conditioned by Climax, No. TRW-3 exhibited a longitudinal crack. The magnitude of the crack precluded the use of this extrusion for forging stock. The four billets were conditioned from extrusion Nos. TRW-1 and 4 as illustrated schematically in Figure 10.



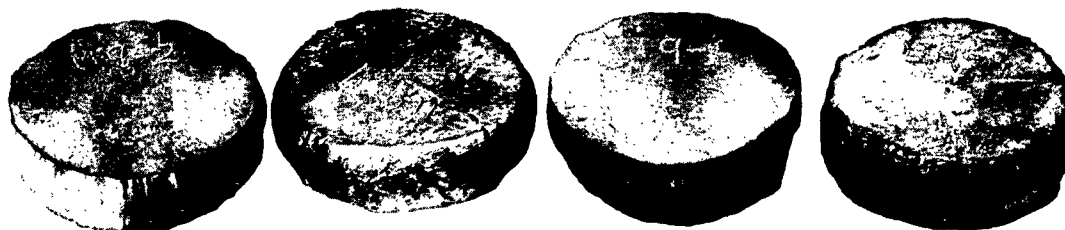
2200°F

2400°F

2600°F

2800°F

A) Stress Relieved at 2500°F - 1 hr.



2200°F

2400°F

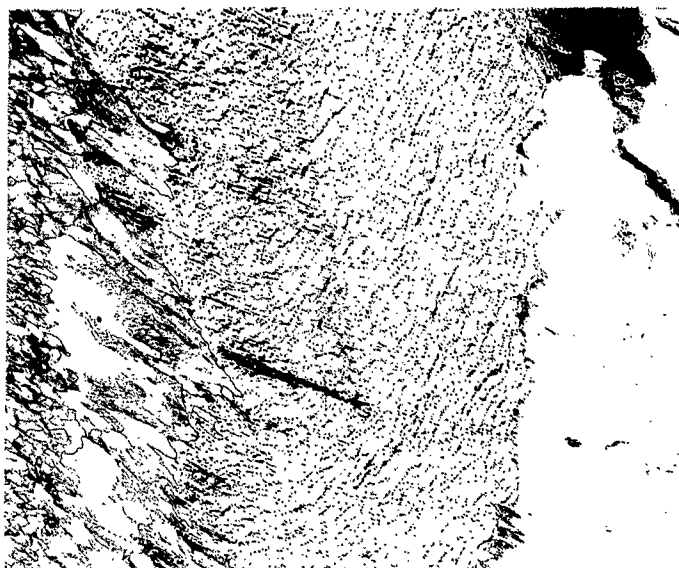
2600°F

2800°F

B) Recrystallized at 2900°F - 1 hr.



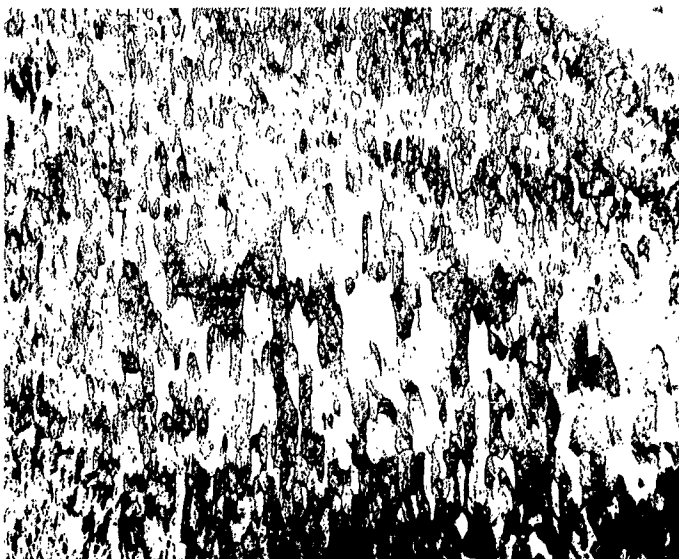
APPEARANCE OF UNALLOYED TUNGSTEN SLUGS AFTER
A 50% UPSET AT THE TEMPERATURES INDICATED



2600°F

07209

A) Stress Relieved Prior to Upsetting



2600°F

07208

B) Recrystallized Prior to Upsetting

MICRO STRUCTURE OF UNALLOYED TUNGSTEN SLUGS
AFTER A 50% UPSET AT 2600°F

50X



Diagram illustrating the structure and dimensions of two cylindrical metal samples, TRW-1 and TRW-4, showing their internal structure and dimensions.

Sample TRW-1 (NO. 100W7480A):

- Sections: NO. 1, NO. 2, NO. 3
- Labels: NO. 1 REX'D, NO. 2 REX'D, NO. 3 S.R.
- Dimensions: 6.6" (between sections), 2" (sample slice), 6.6" (cropped length), 32" (total length)
- Labels: SAMPLE SLICE LEAD, MIDDLE SAMPLE SLICE

Sample TRW-4 (NO. 100W7481B):

- Sections: NO. 1, NO. 2, NO. 3
- Labels: NO. 1 S.R. *, NO. 2 S.R., NO. 3 S.R.
- Dimensions: 6.6" (between sections), 2" (sample slice), 6.6" (cropped length), 38" (total length)
- Labels: SAMPLE SLICE LEAD, SAMPLE SLICE MIDDLE

Legend:

- * BILLET - SURFACE CRACK
- S.R. = STRESS RELIEVED
- REX'D = RECRYSTALLIZED

* BILLET - SURFACE CRACK
S.R. = STRESS RELIEVED
REX'D= RECRYSTALLIZED

18



E. Micro and Macro - Structures

The as-extruded microstructures of the center sections of extrusion Nos. TRW-1 and 4 are shown in Figures 11 and 12. A comparison with the lead sections of these extrusions (Figures 4 and 6) indicated TRW-1 was recrystallized to a larger degree at the center section while TRW-4 appears to be essentially fully cold worked at the center section. This becomes more apparent upon inspection of the macrosections shown in Figures 13 and 14. Note the contrast in size between the recrystallized grains and the larger cast-extruded grains.

F. Hardness

Hardness values were determined by traversing across the lead and center sections of extrusion Nos. TRW-1 and 4. The results, listed in Table I, correspond to those anticipated from observation of the micro and macrostructures, e.g., higher hardness values are exhibited for the cold worked center section of TRW-4 as compared to the recrystallized center section of TRW-1.

G. Inspection

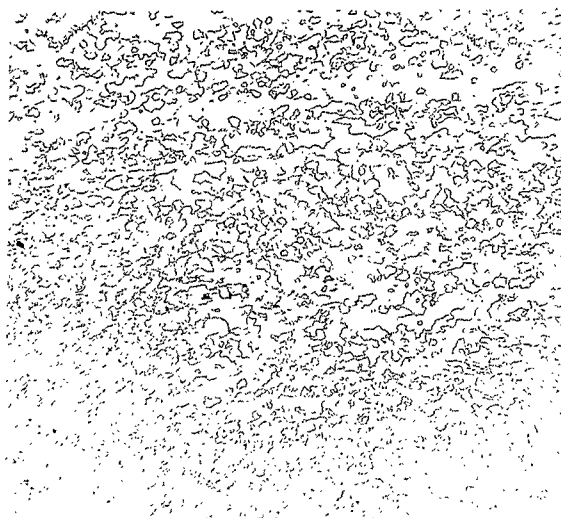
1. Surface

The four forging billets were machined by Climax to the specified 3.850" diameter by 6.600" length. Fluorescent penetrant inspection (post emulsification zyglo) performed at both Climax and TAPCO revealed slight surface "grain pull" indications. The billets were ground to forging billet dimension at TAPCO (3.750" diameter x 6.500" long) and re-zygloed. Results of the inspection revealed no surface discontinuities. TAPCO fluorescent penetrant inspection was performed to MIL-6866-A standards.

The representative surface appearance of the cast-extruded unalloyed tungsten ground to forging billet dimensions is shown in Figure 15.

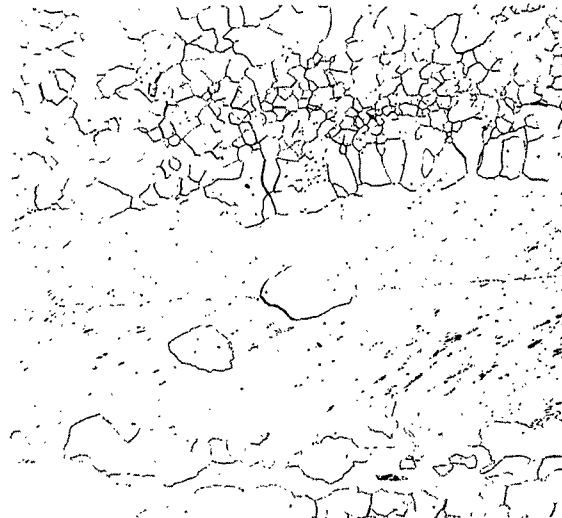
2. Ultrasonic Testing

Ultrasonic testing at Climax indicated the forging billets to be free from internal defects. Similar testing by TAPCO utilizing previously reported techniques^(2, 3) confirmed Climax results. It should be noted, however, that the coarse grain inherent in conventional arc casting techniques limits to some degree the test sensitivity⁽²⁾.



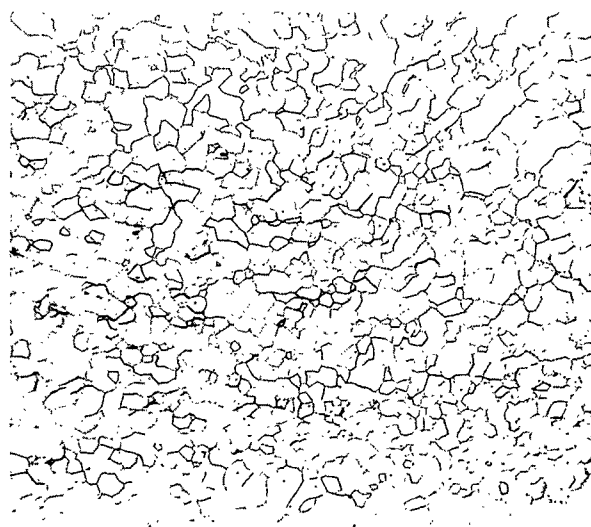
SURFACE

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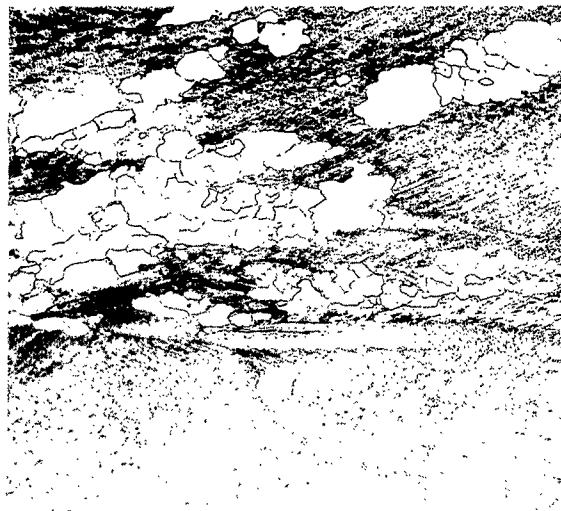


MID RADIUS

7214

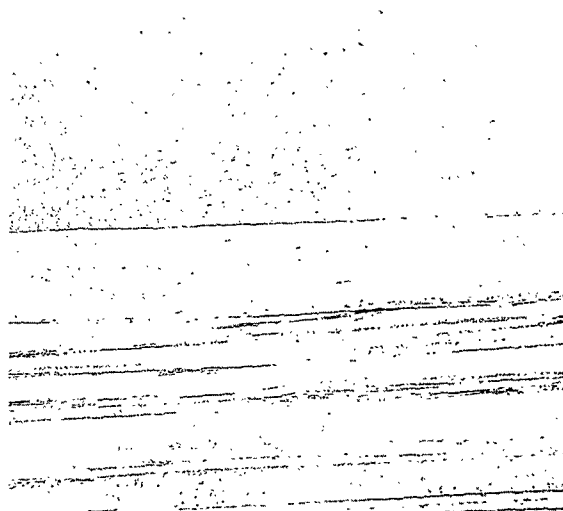
**AS EXTRUDED MICRO STRUCTURES OF CENTER SECTION
OF EXTRUSION NO. TRW-1**

50X



SURFACE

07207



CENTER

07206

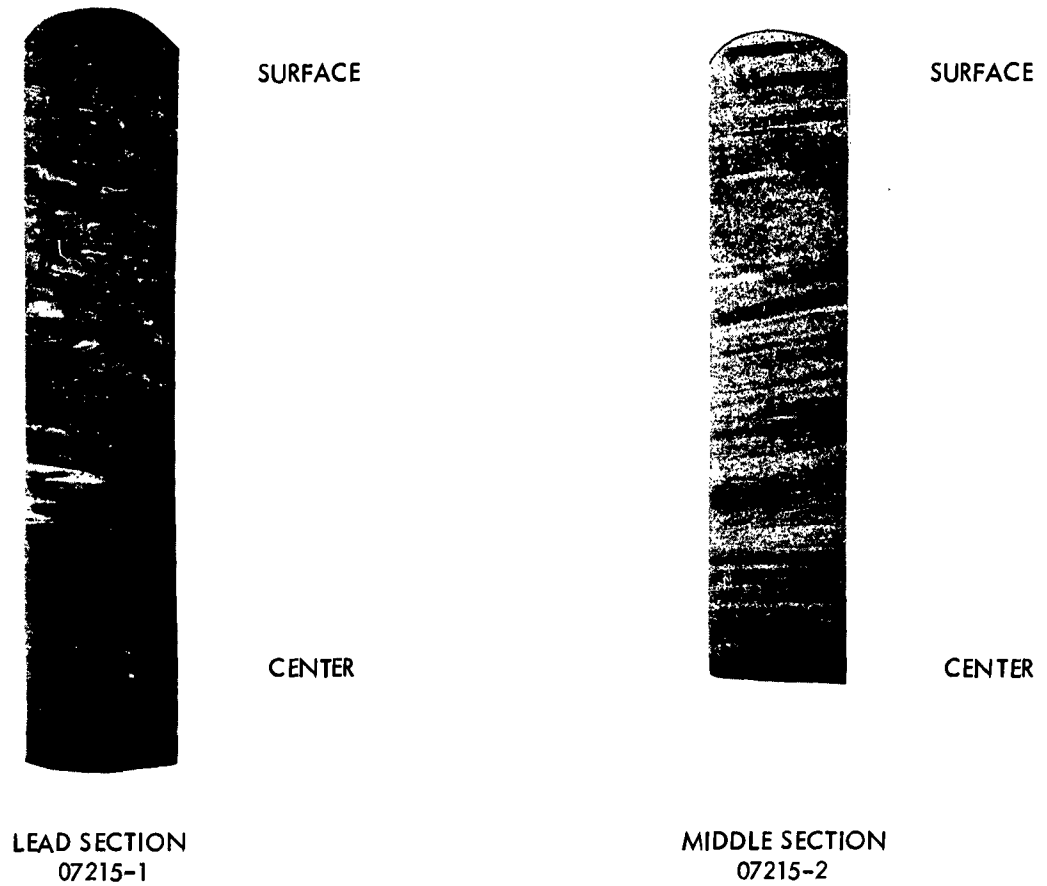


MID RADIUS

07205

AS EXTRUDED MICROSTRUCTURES OF CENTER SECTION OF
EXTRUSION NO. TRW-4

50X



LONGITUDINAL MACRO SECTIONS OF
EXTRUSION NO. TRW-1, AS STRESS RELIEVED 2X

2X



SURFACE

CENTER

LEAD SECTION
07215-3



SURFACE

CENTER

MIDDLE SECTION
07215-4

LONGITUDINAL MACRO SECTIONS OF
EXTRUSION NO. TRW-4, AS STRESS RELIEVED

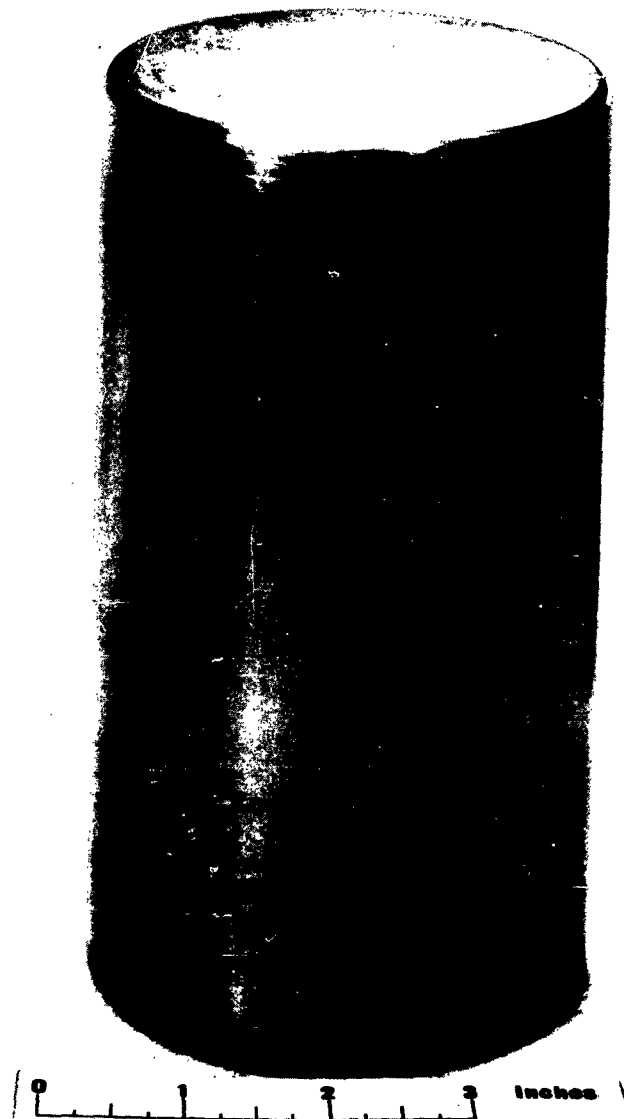
2X



TABLE I
HARDNESS⁽¹⁾ ACROSS TRANSVERSE SECTIONS OF
UNALLOYED TUNGSTEN EXTRUSIONS

<u>Extrusion No.</u>	<u>Location No.⁽²⁾</u>	<u>Lead Section Hardness (R_C)</u>	<u>Center Section Hardness (R_C)</u>
TRW-1 (100W7480A)	1	40.0	40.0
	2	40.0	39.0
	3	39.5	38.5
	4	40.0	38.0
	5	39.0	38.0
	6	39.5	39.0
	7	40.0	39.0
	Average	39.7	38.8
TRW-4 (100W7481B)	1	38.5	43.0
	2	38.0	43.0
	3	39.0	42.5
	4	42.0	42.5
	5	41.0	43.0
	6	42.5	43.5
	7	40.0	43.0
	Average	40.1	42.9

- (1) Each value represents the average of a minimum of four good impressions.
- (2) Location numbers refer to a linear traverse from extrusion surface to center with 1/4" spacing across the transverse faces of the sample slices shown schematically in Figure 10. The traverse was made from the extrusion surface to the extrusion center. Therefore, numbers 1 and 2 represent material close to the extrusion surface, while numbers 6 and 7 represent centrally located material, etc.



07218-5

REPRESENTATIVE SURFACE APPEARANCE OF TUNGSTEN FORGING BILLET
TO BE USED FOR PHASE VI FORGING TRIAL



3. Chemical Analysis

The certified chemical analysis supplied by Climax of the lead and center sections of extrusion Nos. TRW-1 and 4 are listed in Table II. Analytical techniques utilized and limits specified are detailed in Appendix I. The vendor analysis was within the specification limits. Specimens were prepared as previously reported⁽⁶⁾ by TAPCO for duplicate carbon and oxygen analysis. These results are listed in Table III. The carbon and oxygen levels were well within specification except for TRW-4 lead section which borders the upper carbon limit.



TABLE II
CHEMICAL ANALYSIS⁽¹⁾ OF ARC-MELTED AND EXTRUDED
UNALLOYED TUNGSTEN

<u>Element</u>	<u>Extrusion No. TRW-1 (100W7480-A)**</u>		<u>Extrusion No. TRW-4 (100W7481-B)**</u>	
	<u>Lead</u> <u>(ppm)</u>	<u>Mid Section</u> <u>(ppm)</u>	<u>Lead</u> <u>(ppm)</u>	<u>Mid Section</u> <u>(ppm)</u>
C	22	22	22	11
O	7	4	9	6
H	1*	1*	1	1
N	2	1	2	2
Mo	630	505	554	540
Al	10*	10*	10*	10*
Cr	10*	10*	10*	10*
Co	5*	5*	5*	5*
Cu	1*	1*	5*	5*
Fe	16	14	30	25
Mg	1*	1*	1*	1*
Mn	10*	10*	10*	10*
Ni	1*	1*	1*	1*
Pb	20*	20*	20*	20*
Si	20*	20*	20*	20*
Sn	20*	20*	20*	20*
Ti	1*	1*	1*	1*
V	10*	10*	10*	10*
W	Balance	Balance	Balance	Balance

(1) Analysis supplied by vendor (Climax Molybdenum of Michigan).

* Indicates value shown is lowest quantitative result obtainable through standardization of the techniques utilized for unalloyed tungsten. Techniques specified are listed in Appendix 1.

** TRW-X refers to TAPCO No. designation; (100W74...) refers to Climax Molybdenum No. designation.



TABLE III
CARBON AND OXYGEN ANALYSIS OF ARC-MELTED
AND EXTRUDED UNALLOYED TUNGSTEN

<u>Extrusion No.</u>	<u>Position</u>	<u>Determination No.</u>	<u>Carbon⁽¹⁾</u> <u>(ppm)</u>	<u>Oxygen⁽²⁾</u> <u>(ppm)</u>
TRW-1 (100W7480-A)	Lead	1	4	26
		2	<u>4</u>	<u>25</u>
		Average	4	26
	Mid Section	1	1	33
		2	<u>3</u>	<u>27</u>
		Average	2	30
TRW-4 (100W7481-B)	Lead	1	51	39
		2	<u>63</u>	<u>40</u>
		Average	57	40
	Mid Section	1	10	20
		2	<u>14</u>	<u>19</u>
		Average	12	20

- (1) Leco Conductometric
(2) Inert Gas Fusion

Analysis performed by Grobaugh Testing Laboratory, Cleveland, Ohio



V REFERENCES

1. "Tungsten Forging Development Program", First Interim Technical Progress Report, Contract AF 33(600)-41629, August 1960, Materials Processing Department, Thompson Ramo Wooldridge Inc.
2. "Tungsten Forging Development Program", Second Interim Technical Progress Report, Contract AF 33(600)-41629, December 1960, Materials Processing Department, Thompson Ramo Wooldridge Inc.
3. "Tungsten Forging Development Program", Third Interim Technical Progress Report, Contract AF 33(600)-41629, March 1961, F. N. Lake and E. J. Breznyak, Thompson Ramo Wooldridge Inc.
4. "Tungsten Forging Development Program", Fourth Interim Technical Progress Report, Contract AF 33(600)-41629, May 1961, F. N. Lake, E. J. Breznyak, and G. S. Doble, Thompson Ramo Wooldridge Inc.
5. "Tungsten Forging Development Program", Fifth Interim Technical Progress Report, Contract AF 33(600)-41629, November 1961, F. N. Lake, Thompson Ramo Wooldridge Inc.
6. "Tungsten Forging Development Program", Sixth Interim Technical Progress Report, Contract AF 33(600)-41629, September 1962, F. N. Lake, Thompson Ramo Wooldridge Inc.
7. "Tungsten Forging Development Program", Seventh Interim Technical Progress Report, Contract AF 33(600)-41629, E. J. Breznyak and F. N. Lake, Thompson Ramo Wooldridge Inc.



VI PROGRAM FOR THE NEXT PERIOD

During the next period the Phase VI program will be completed. This will include:

1. Initial forging trials with gridded composite steel billets to determine the metal flow patterns and with the four unalloyed tungsten billets discussed in this report.
2. Modification of tooling as required.
3. Evaluation of properties of tungsten forgings produced from initial billets of hot-cold worked and fully recrystallized microstructures.
4. Selection of optimum forging billet microstructure.
5. Procurement of eight additional unalloyed tungsten forging billets.
6. Additional forging to determine optimum process parameters.
7. Property evaluation of forgings produced to demonstrate the reproducibility of the process.



TAPCO a division of
Thompson Ramo Wooldridge Inc.

VII Appendix I

Forging Billet Procurement Specification



PROCESSING AND MATERIAL SPECIFICATION NO. 2135-8A
ARC MELTED AND EXTRUDED UNALLOYED TUNGSTEN FORGING BILLETS
CLIMAX MOLYBDENUM COMPANY OF MICHIGAN
11 February 1963

The intent of this tentative specification is to insure quality of the vacuum arc melted and extruded unalloyed tungsten forging billets procured by Thompson Ramo Wooldridge Inc. for an experimental program.

A. INGOT MELTING

1. Starting materials shall be introduced into a PSM vacuum arc furnace wherein they shall be compressed to electrode, resistance sintered, and fed directly into the melt.

B. INGOT EXTRUSION PROCEDURE

1. Desired extrusion area reduction ratio shall be $4/1$ or greater. A reduction ratio lower than $3.5/1$ shall not be acceptable.
2. Extrusion temperatures shall be such that cold worked microstructures are produced and retained in the extruded stock.
3. Any extrusion stress relief treatments utilized shall not impart recrystallization.

C. EXTRUSION SECTIONING

1. After lead and butt portions of the extrusions have been cropped, each extrusion shall be sectioned at the lead, mid-point*, and butt positions to provide $1/4"$ to $1/2"$ thick inspection discs. A half section of each inspection disc shall be appropriately identified and delivered to Thompson Ramo Wooldridge Inc. for inspection as described in Section G.
2. Material for chemical analyses as discussed in Section E shall be removed from the inspection discs within an area representative of the finish machined forging billet interiors.

* "Mid-point" position shall be interpreted in this specification as the closest position to the mid-point of the cropped extrusion which can be obtained without sacrifice of forging billets; i.e., if an even number of forging billets could be sectioned from a cropped extrusion the actual "mid-point" inspection disc could be obtained, whereas if an odd number of forging billets could be sectioned from a cropped extrusion the "mid-point" inspection disc would represent material one-half forging billet length distant from the actual mid-point.



D. BILLET MACHINING AND ETCHING

1. Each forging billet shall be a right cylinder 3.850" diameter ± 0.020 " by 6.600" long ± 0.060 ".
2. Each forging billet shall have a surface finish of 400 rms or better on all surfaces.
3. Each finish machined forging billet shall be lightly etched prior to inspection specified in Section E. Paragraph 1, to remove any smearing of possible surface defects during machining. Care shall be exercised during etching such that grain boundaries do not show as defects during inspection.

E. BILLET INSPECTION

1. Each forging billet shall be inspected for surface and internal defects by visual, ultrasonic, and super zygo fluorescent penetrant inspection (post emulsification type). No billet shall be shipped with defects or questionable indications without prior written approval from Thompson Ramo Wooldridge Inc.
2. Inspection discs taken from each extrusion at lead, mid-point, and butt positions as specified in Section C, Paragraph 2, shall be analyzed for carbon, oxygen, hydrogen, nitrogen, and general metallic impurities. Analytical methods required and element limits specified are listed below:

<u>Element</u>	<u>Method</u>	<u>Maximum Limit</u> <u>ppm</u>
C	Leco Conductometric	50
O	Vacuum Fusion	20
H	"	10
N	"	15
Al.	Spectrographic	10
Co	"	5
Cr	"	20
Cu	"	5
Fe	"	50
Mg	"	20
Mn	"	10
Mo	"	1000
Ni	"	20
Pb	"	20
Si	"	50
Ti	"	20
V	"	20
Sn	"	40
W	-	Balance



No forging billet shall be shipped from an extrusion with an analysis greater than the maximums limited above without prior written approval from Thompson Ramo Wooldridge authorizing such shipment.

F. BILLET SHIPMENT

1. Each forging billet shall be packed for shipment in a suitable container.
2. No forging billet shall be shipped without:
 - a) Certification that it was manufactured and processed in exact accordance with this specification.
 - b) Certified results of ultrasonic and super zyglo fluorescent penetrant inspection.
 - c) Certified chemical analyses of the inspection discs from the extrusion from which the billet was prepared.
 - d) Identification as to extrusion number and billet location within the extrusion with the billet lead face identified corresponding to the extrusion lead end.

G. BILLET ACCEPTANCE

1. Acceptance of each forging billet by Thompson Ramo Wooldridge Inc. is contingent upon:
 - a) Results of microstructure examination of extrusion inspection discs. Cause for forging billet rejection shall be the inability to produce and retain a 90% minimum cold worked structure in the extruded stock during processing as determined by optical microscopy of longitudinal surfaces electrolytically polished and etched, and observed at a magnification no higher than 250X. 100% cold worked structure is desired.
 - b) Results of ultrasonic, super zyglo fluorescent penetrant, and surface finish inspection by Thompson Ramo Wooldridge Inc. after each delivery.
 - c) Results of chemical analyses for carbon, oxygen, hydrogen, and nitrogen by Thompson Ramo Wooldridge Inc. after delivery if deemed necessary by Thompson Ramo Wooldridge Inc. Samples used for chemical analyses shall be taken from any portion



of the inspection discs within an area representative of the finished machined billet interiors. Samples shall be taken in triplicate. No billets shall be rejected for this cause unless the average analysis from the three samples exceeds the following limits:

<u>Element</u>	<u>Method</u>	<u>Maximum Level</u> <u>ppm</u>
C	Leco Conductometric	60
O	Vacuum Fusion, Inert Gas Fusion, or Leco Conductometric	60
H	Vacuum Fusion	20
N	Micro Kjeldahl or Vacuum Fusion	30

In the event of a dispute over carbon, oxygen, hydrogen, and nitrogen analysis of the extrusion inspection discs, Horizons Inc., 2905 East 79th Street, Cleveland 4, Ohio shall conduct referee analyses.

2. Expense for all inspection and analytical efforts described in Section G, Paragraph 1, except referee efforts, shall be borne by Thompson Ramo Wooldridge Inc. Expense of any necessary referee efforts shall be shared equally by Thompson Ramo Wooldridge Inc. and Climax Molybdenum Co. of Michigan.
3. Prior written approval by Thompson Ramo Wooldridge Inc. authorizing shipment of deviated billets shall not indicate acceptance.



VIII DISTRIBUTION LIST

ASD (ASRCTB)
Wright-Patterson AFB, Ohio (4)

ASD (ASRC, Dr. A. M. Lovelace)
Wright-Patterson AFB, Ohio

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Wright-Patterson AFB, Ohio

ASD (ASRCMC, Mr. W. C. Ramke)
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Washington 5, D. C.

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Alloyd Research Corporation
Attention: Mr. Louis Mager
General Manager
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Chicago 16, Illinois

Arcturus Manufacturing Corporation
Attention: Chief Engineer
4301 Lincoln Boulevard
Venice, California

Armour Research Foundation
Metals Research Department
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Chicago 16, Illinois

ASTIA
Arlington Hall Station
Arlington 12, Virginia (4)

Atomic Products Division
General Electric Company
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Pleasanton, California

Babcock & Wilcox Company
Attention: Chief Metallurgist
Beaver Falls, Pennsylvania

Baldwin-Lima-Hamilton
Attention: Mr. George Lessis
111 5th Avenue
New York 3, New York

6539 Test Group
Attention: DGSCH
Edwards AFB, California

Battelle Memorial Institute
Defense Metals Information Center
505 King Avenue
Columbus 1, Ohio

Bell Aerospace Corporation
Attention: Manager, Production Eng.
P. O. Box 482
Fort Worth 1, Texas

Bell Aerosystems Company
Attention: Manager, Production Eng.
Buffalo 5, New York



Bendix Products Division
Bendix Aviation Corporation
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401 N. Bendix Drive
South Bend, Indiana

The Boeing Company
Materials Mechanical & Structures Branch
Systems Management Office
P. O. Box 3707
Seattle 24, Washington

Cameron Iron Works
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Vice President and Manager
Special Products Division
P. O. Box 1212
Houston 1, Texas

Canton Drop Forging & Manufacturing Co.
Attention: Quality Control Manager
2100 Willett Avenue
Canton 2, Ohio

Chance Vought Corporation
Vought Aeronautics Division
Attention: Chief Librarian
P. O. Box 5907
Dallas, Texas

Climax Molybdenum Co. of Michigan
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Vice President
14410 Woodrow Wilson
Detroit 38, Michigan

Commander
Army Ballistic Missile Agency
Research Laboratory
Redstone Arsenal, Alabama

Crucible Steel Company of America
Midland Research Laboratory
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Crucible Steel Company of America
Central Research Laboratory
234 Atwood Street
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Long Beach 8, California

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Douglas Aircraft Company, Inc.
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Fansteel Metallurgical Company
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General Office
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General Dynamics Corporation/Convair
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General Electric Company
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Cleveland Wire Plant
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Hercules Powder Company
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Beehive Bank Building
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California Institute of Technology
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Rohr Aircraft Corporation
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Stanford Research Institute
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Menlo Park, California



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Special Metals, Inc.
Research Librarian
New Hartford, New York

Stauffer Metals Company
Division of Stauffer Chemical Co.
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Steel Improvement & Forge Company
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Attention: Chief Engineer
Towanda, Pennsylvania

Taylor Forge & Pipe Works
Attention: Special Products Manager
P. O. Box 485
Chicago 90, Illinois

Thiokol Chemical Corporation
Attention: Mr. Patrick V. McAllister
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Transue & Williams Steel Forging Corp.
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Sales Manager
Allience, Ohio

Union Carbide Metals Company
Division of Union Carbide Corporation
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U. S. Bureau of Mines
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Albany, Oregon

Universal Cyclops Steel Corp.
Refractomet Division
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Wah Chang Corporation
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Kansas City, Missouri

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Churchill Borough
Pittsburgh 35, Pennsylvania

Wyman-Gordon Company
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Materials Department, TAPCO
Thompson Ramo Wooldridge Inc.
Cleveland 17, Ohio
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E. J. Breznyak
19 May 1963 40 p. incl.
illus., tables (Proj. 7-797)
(ASD TR 7-797 VIII)
(Contract AF 33(600)41629)
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